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# EFFECTS OF METHADONE ON ALTERNATIVE FIXED-RATIO FIXED-INTERVAL PERFORMANCE: LATENT INFLUENCES ON SCHEDULE-CONTROLLED RESPONDING

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Effects of methadone on pigeons' key pecking were examined under four conditions selected to analyze the control of behavior under alternative fixed-ratio fixed-interval schedules. In Condition 1, pigeons pecked under one of three different alternative schedules (alternative fixed-ratio 50 fixed-interval 90 s, alternative fixed-ratio 75 fixed-interval 90 s and alternative fixed-ratio 200 fixed-interval 90 s) each week. In Condition 2, fixed-ratio 50 or fixed-ratio 75 schedules were in effect during baseline sessions, and alternative fixed-ratio 50 fixed-interval 90-s or alternative fixed-ratio 75 fixed-interval 90-s schedules were in effect during sessions in which methadone was administered. In Condition 3, effects of methadone on key pecking maintained under fixed-ratio 50 and fixed-ratio 75 schedules were examined, whereas in Condition 4 the effects of methadone on key pecking under a fixed-interval 90-s schedule as well as fixed-ratio 50 and fixed-ratio 75 schedules were investigated. Control by the fixed-interval contingency was assessed by computing the proportion of total session reinforcers delivered under the fixed-interval schedule. Methadone administration (0.5–4.0 mg/kg) shifted the predominant source of schedule control under the alternative schedule from the fixed-ratio schedule to the fixed-interval contingency. This shift was dependent on methadone dose and fixed-ratio size. Control by the fixed-interval contingency was greatest following extensive exposure to the interval component embedded within the alternative schedule (Condition 1), but was apparent to a lesser degree with even very limited exposure to the alternative fixed-ratio fixed-interval schedule (Condition 2). Interreinforcement intervals comparable to those under a fixed-interval schedule were not observed under the fixed-ratio schedules presented alone (Condition 3). Repeated exposure to the fixed-interval contingency outside the context of the alternative fixed-ratio fixed-interval schedule did not engender performance changes under a fixed-ratio schedule which would mimic those of increased fixed-interval contingency control (Condition 4). These data suggest that drug administration can be used to unmask the influence of contingencies that are latent under baseline conditions and reveal influences of both past and present environmental variables.

*Key words:* alternative schedules, methadone, fixed ratio, fixed interval, schedule history, key peck, pigeons

Performances maintained under fixed-ratio (FR), variable-ratio, fixed-interval (FI), and variable-interval reinforcement schedules can be identified by reliably occurring characteristics. Differences in overall response rates, postreinforcement pause times, interresponse time (IRT) frequencies, and overall distribution of responding within the interreinforcement interval (e.g., the "FI scallop") are associated with each schedule type. These characteristics are determined, in part, by variables that are not specified directly by the reinforcement schedule. Such *indirect variables* (Zeiler, 1977) associated with a given schedule are contrasted with the *direct variables,* that is, the temporal and/or response requirements that must be met for reinforcement. Under an FI reinforcement schedule, for instance, reinforcement density (number of reinforcers per unit time) is determined by a direct variable, the temporal requirement of the schedule. Under an FR schedule, however, maximum reinforcement density is determined indirectly by response rate and pause time.

After extensive exposure to a contingency, schedule and performance variables reach a state of equilibrium, with some factors exerting greater control than others. Equilibrium is manifested in the regularly recurring performance patterns within and across experimental sessions. Under steady state conditions, however, some variables that operated previ-

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ously to shape current behavior may be latent. That is, conditions exist under current contingencies, but their influence may not be apparent in features of the organism's behavior when other conditions prevail.

Complex schedules can be used to study the relations among multiple sources of schedule control. Complex schedule combinations are reinforcement requirements involving the simultaneous confluence of ratio and interval contingencies (Thompson & Grabowski, 1972; Thompson & Lubinski, 1986). Such schedules incorporate direct and indirect schedule variables operating in basic ratio and interval schedules, producing novel performance characteristics. Drug administration may alter the degree of control by the direct or indirect variables present in a complex schedule. The relative contribution of the affected schedule variable in maintaining performance rate and pattern during baseline conditions will influence the degree to which the operant behavior is altered by drug administration (see Thompson, 1984, pp. 34–36). Controlling variables operating during combined contingencies may be disrupted by the drug, and latent variables that were not apparent during baseline conditions may be unmasked by allowing them to exert observable control over the ongoing operant. Drug administration, therefore, can be a useful tool in assessing the relative contribution of controlling variables in complex schedule arrangements (see Grove & Thompson, 1970).

Ferster and Skinner (1957) described an alternative reinforcement schedule in which the reinforcement of performance on a single operandum is programmed by either a ratio or interval schedule, whichever is satisfied first. Therefore, under an alternative FR 50 FI 90-s schedule, reinforcement occurs (a) following the first response after 90 s has elapsed provided that 50 responses have not been emitted; or (b) after the completion of 50 responses provided that 90 s has not elapsed. Rider (1980), using rats as subjects, examined performance under alternative FR FI food presentation schedules while varying the FR and FI parameter values. Performance under the alternative FR FI schedule depended on the FR size relative to the FI value. As the FR value increased, response rates decreased and postreinforcement pause time increased. Furthermore, the response pattern during the interreinforcement interval shifted from alternations of zero and high constant rates associated with FR schedules to the gradual positively accelerated response pattern associated with FI schedules (Ferster & Skinner, 1957). In addition, as the FR value increased, the proportion of reinforcers delivered under the FI contingency approached 1.0. Thus, when the FR value was low, the alternative schedule tended to produce performance typically associated with an FR schedule; as the FR value increased, the schedule engendered performance with characteristics associated with an FI schedule.

In the present experiment, effects of methadone, a synthetic opioid used in the detoxifying and maintenance treatment of heroin addicts, were examined on key pecking maintained under alternative FR FI food reinforcement schedules. Under FR and FI schedules, methadone typically decreases overall operant response rates (Bigelow & Thompson, 1971; McMillan, McGivney, & Hardwick, 1980; McMillan, Wolf, & Carchman, 1970). In addition, relative response rate reductions are greater under ratio than under interval schedules (Thompson, Honor, Verchota, & Cleary, 1984). In the present experiment, the degree to which interval and ratio contingencies were satisfied in the alternative FR FI arrangement was examined following administration of various methadone doses. Under these conditions, control of behavior shifted from the FR to the FI schedule as FR size and methadone dose increased. Because reinforcement schedule history influences the behavioral effects of drug administration (e.g., Barrett, 1985; Urbain, Poling, Millam, & Thompson, 1978), including methadone (Nader & Thompson, 1987), effects of methadone on key pecking under alternative FR FI schedules by pigeons with limited exposure to the FI contingency during training were also examined. The extent to which the FI contingency would have been satisfied following methadone administration was examined in relation to key-peck rate changes by pigeons pecking under simple FR reinforcement schedules. Because subjects in the first condition were found to have had extensive exposure to the FI contingency via the alternative schedule with the highest FR value, effects of methadone on the proportion of FR interreinforcement intervals equal to or greater than the FI value were examined in pigeons given exposure to the FI contingency comparable to ex-

posure to the alternative schedule with the highest FR value by subjects in the first condition.

## METHOD

### *Subjects*

Fifteen experimentally naive adult female White Carneau pigeons, maintained at 80% of their free-feeding weights by postsession feedings, served as subjects. The birds were housed individually with continuous access to water and grit in a colony room maintained at 24 °C with 24-hr illumination.

### *Apparatus*

Experimental sessions were conducted in four sound-attenuating operant chambers (BRS/LVE) each containing three response keys and a solenoid-operated feeder that was illuminated during operation. Each chamber was illuminated with an overhead houselight, and white masking noise was present in the surrounding experimental room throughout experimental sessions. Programming of the schedule conditions and behavioral recording were accomplished using an Apple II plus® microcomputer. Cumulative recorders (Gerbrands) provided a visual record of cumulative key pecks in time for each session.

### *Drug Preparation and Administration*

Methadone hydrochloride powder (Eli Lilly, Inc.) was dissolved in isotonic saline (0.9%) to obtain a constant injection volume of 1.0 mL/kg. Methadone doses (0.5, 1.0, 2.0, 2.5, 3.0, and 4.0 mg/kg) are expressed in terms of total salt. Injections were given in the breast muscle 30 min before experimental sessions. Isotonic saline injection was used as a control.

### *Procedure*

Initially, the pigeons' key pecks were autoshaped (Brown & Jenkins, 1968) such that a peck to the center key (illuminated white) produced 4-s access to mixed grain. After the first key peck, mixed grain was available following each peck (CRF). Once the pigeons pecked reliably, the final schedule conditions were introduced gradually. Each session began with the illumination of the houselight and the center key. The experimental sessions were 45 min long and were conducted at the same time of day 6 days per week.

Under the first condition, Subjects P-164, P-10, P-11, and P-12 were exposed to alternative FR 50 FI 90-s, alternative FR 75 FI 90-s, and alternative FR 200 FI 90-s schedules. To minimize experience with the FI contingency, 3 additional birds (P-1, P-2, and P-4) were exposed to FR 50 and FR 75 schedules during baseline sessions. During the methadone administration sessions, however, either an alternative FR 50 FI 90-s or alternative FR 75 FI 90-s schedule operated incorporating the same FR value that had been used during the baseline. In a third condition, 4 pigeons (P-21, P-22, P-23, and P-24) were studied under FR 50 and FR 75 schedules, whereas in the final condition, 4 birds (P-5, P-6, P-8, and P-9) were exposed to an FI 90-s schedule in addition to the FR schedules. Each week, under all conditions, a different schedule was in effect; the order in which schedules were presented from week to week was randomized. During the first session of a week in which the schedule value was changed from the previous week, pigeons' key pecking rapidly adjusted to the newly implemented schedule. Once the birds had been exposed to each of the schedule values (at least five consecutive sessions of each), methadone injections were administered every Thursday, and saline control injections were administered on Wednesdays. Schedule values were not changed until the following Sunday; Friday's session assessed recovery to baseline following drug administration. The same schedule value was used for every session in a given week; therefore, four sessions using a given schedule occurred prior to methadone administration and one followed. Each methadone dose was tested once for each schedule value. The methadone dose administered varied unpredictably each week.

## RESULTS

Figure 1 shows cumulative records of key pecking by subjects in Condition 1 during sessions following saline and at the highest dose of methadone that did not completely eliminate pecking (either 2.0 or 3.0 mg/kg) under the alternative FR 50 FI 90-s and alternative FR 75 FI 90-s schedules. Under saline, high steady peck rates resulted under both schedules with almost all reinforcers produced by completion of the FR schedule. Following these doses of methadone, however, most reinforcers were

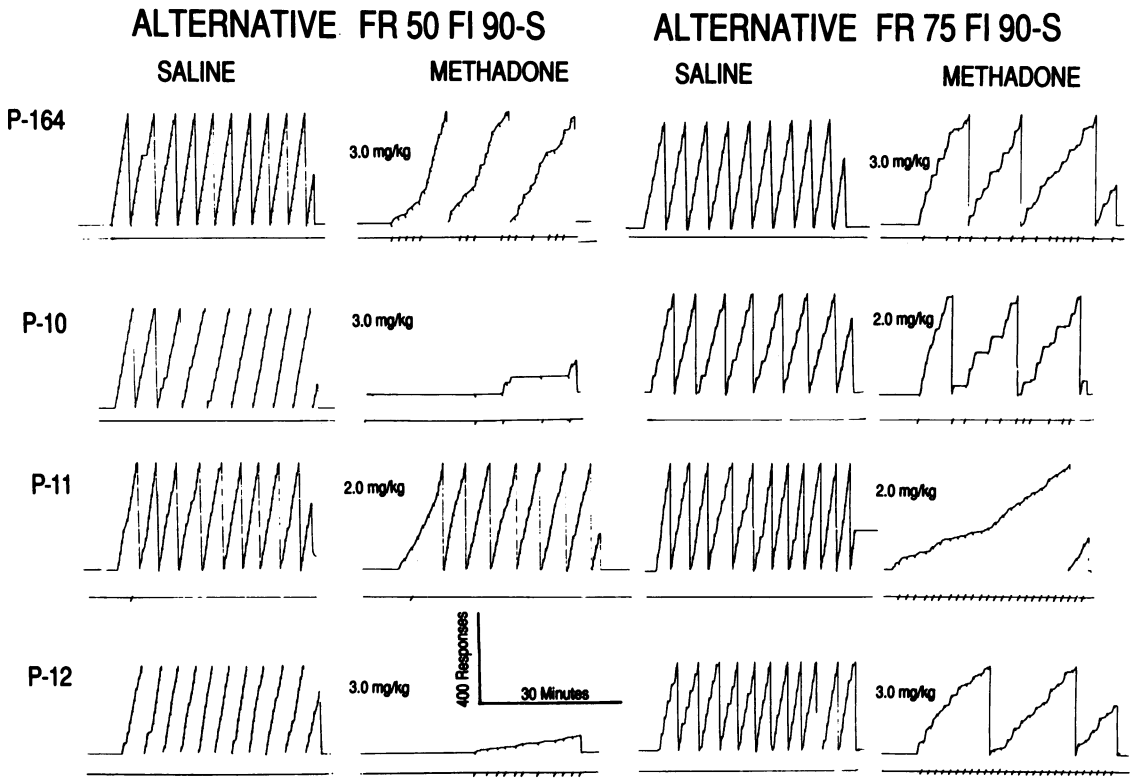


Fig. 1. Cumulative key-peck records of the effects of saline and 2.0 or 3.0 mg/kg methadone on performance under alternative FR 50 FI 90-s and alternative FR 75 FI 90-s schedules by subjects in Condition 1. Saline records are from one of the sessions preceding the drug session. Depressions of the event pen indicate reinforcers earned by fulfilling the FI 90-s contingency.

earned by fulfilling the FI requirement. In addition, several response patterns emerged under methadone. The first was an FI scallop pattern (P-164, alternative FR 75 FI 90 s, 3.0 mg/kg; P-12, alternative FR 75 FI 90 s, 3.0 mg/kg). A second pattern was characterized by low rates of pecking distributed irregularly throughout the interreinforcement interval (P-11, alternative FR 75 FI 90 s, 2.0 mg/kg; P-12, alternative FR 50 FI 90 s, 3.0 mg/kg). Subject P-164's performance contained combinations of these patterns. Finally, negatively accelerated key-peck patterns occurred at the beginning of some methadone sessions (P-164, alternative FR 50 FI 90 s, 3.0 mg/kg; P-11, alternative FR 75 FI 90 s, 2.0 mg/kg; P-12, alternative FR 75 FI 90 s, 3.0 mg/kg).

Methadone substantially altered the performance of only 1 bird (P-11) under the alternative FR 200 FI 90-s schedule. Cumulative records of performance by P-11 under this schedule following saline, 0.5, and 1.0 mg/kg methadone are presented in Figure 2. Performance under saline manifested characteristic FI scallop patterns. When methadone was administered, high key-peck rates sufficient to fulfill the FR 200 requirement were engendered early in the session. For the remainder of the session, reinforcement was earned consistently under the FI 90-s contingency.

Figure 3 compares the effects of methadone on key-peck rates under alternative FR FI schedules by subjects in Conditions 1 and 2. In Condition 1, subjects were exposed to the alternative FR FI schedule during baseline and drug sessions. Thus, birds in Condition 1 received extensive exposure to the FI contingency through the alternative FR 200 FI 90-s schedule sessions and occasionally during baseline sessions of the other alternative schedules. Subjects under Condition 2, on the other hand, were exposed to the alternative FR FI schedule

(and hence the FI contingency) only during sessions in which methadone was administered. Decreases in pecking due to methadone under the alternative FR 50 FI 90-s and alternative FR 75 FI 90-s schedules were comparable in both groups. Key-peck rates of 3 subjects (P-164, P-10, and P-12) under the alternative FR 200 FI 90-s condition were reduced (compared with saline) by the 2.0 and 3.0 mg/kg methadone doses to a lesser degree than rates under the alternative FR 50 FI 90-s and alternative FR 75 FI 90-s schedules. Pigeon P-12's key-peck rate under the alternative FR 200 FI 90-s schedule did not deviate significantly from saline rates at the three highest doses.

Effects of methadone on key pecking during conditions in which the alternative FR FI schedule was never in effect (Conditions 3 and 4) are shown in Figure 4. In general, rates under the FR 50 and FR 75 schedules were reduced by methadone administration similar to the degree by which they were reduced when these schedules were components in an alternative schedule arrangement (cf. Figure 3). However, pecking was eliminated more readily when maintained under a simple FR schedule (Condition 3: Figure 4, left panel) than under alternative schedules (see Figure 3), or following a history of pecking under an FI 90-s schedule (Condition 4: Figure 4, right panel). Under the FI 90-s schedule, methadone produced key-peck rate increases at some doses for 3 subjects (P-6, P-8, and P-9). Table 1 contains means and standard errors of key-peck rates under saline for subjects in all conditions.

The degree to which methadone administration altered the predominant variables controlling pecking under alternative FR FI reinforcement schedules was assessed by examining the proportion of total reinforcers earned under the FI contingency. The proportion of reinforcers earned 90 s (the FI value) or more since the previous reinforcement (or, in the case of the first reinforcer, since the onset of the session) during Conditions 3 and 4 are plotted in the lower half of Figure 5. Because saline values for subjects in the second condition were obtained during sessions in which only the FR schedules were in effect, these values are the proportion of reinforcers earned after 90 s or more had elapsed since previous reinforcement. The top half of Figure 5 shows

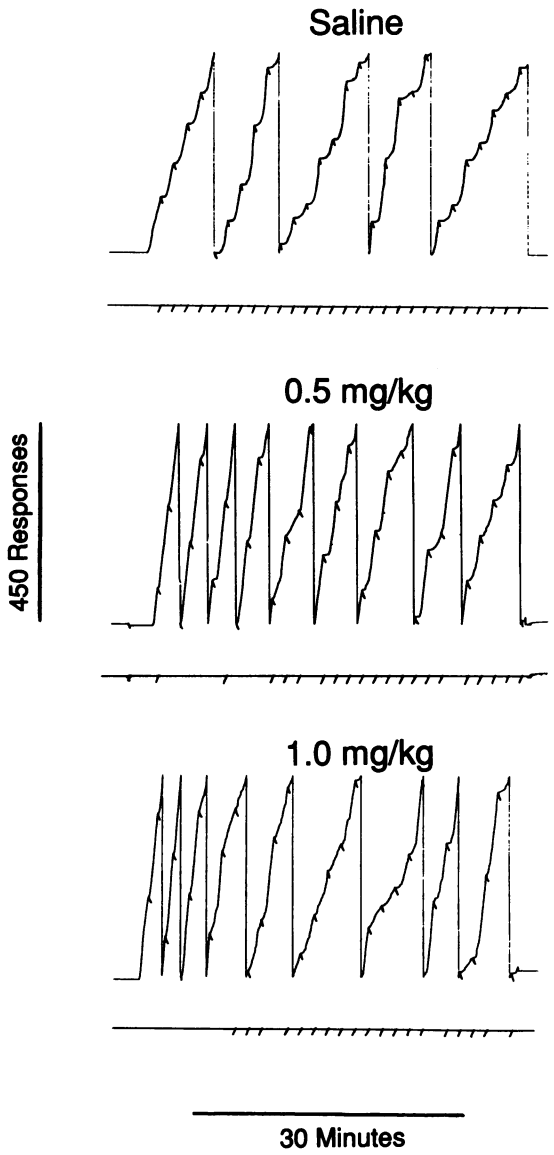


Fig. 2. Cumulative key-peck records of the effects of saline and 0.5 and 1.0 mg/kg methadone on performance under the alternative FR 200 FI 90-s schedule by Subject P-11. Saline records are from one of the sessions preceding the drug sessions. Depressions of the event pen indicate reinforcers earned by fulfilling the FI 90-s contingency.

the proportion of total reinforcers earned under the FI contingency of the alternative FR 50 FI 90-s and alternative FR 75 FI 90-s schedules by each bird under the first two conditions. Tables 2 and 3 show absolute values from which these data are derived. Reinforcers were rarely earned under the FI contingency

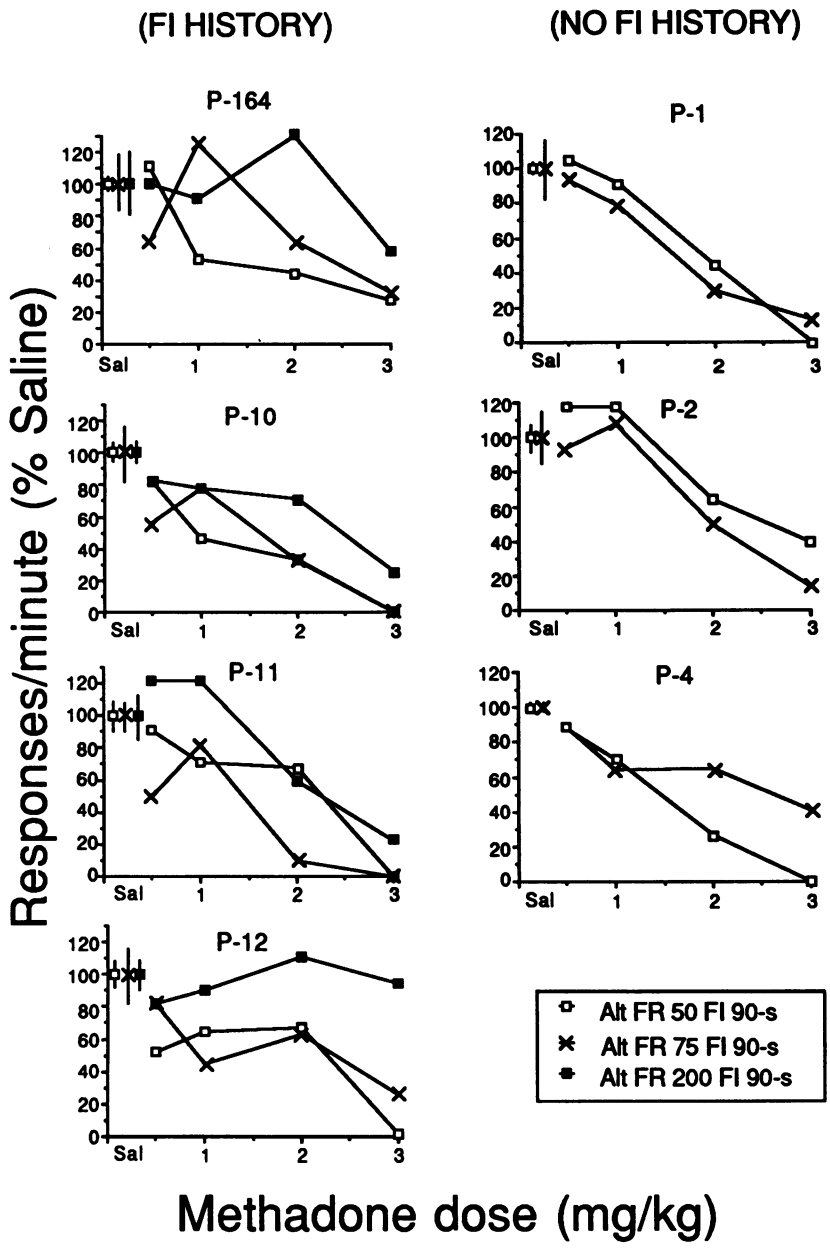


Fig. 3. Effects of methadone on key-peck rates under alternative FR 50 FI 90-s, alternative FR 75 FI 90-s, and alternative FR 200 FI 90-s (Condition 1 only) schedules by subjects in Groups 1 and 2. Detached points to the extreme left denote mean saline measures under each schedule ±*SEM*.

in both schedules when saline was administered. The proportion of reinforcers earned under the FI contingency was positively related to methadone dose. For both groups, this tendency was greater under the alternative FR 75 FI 90-s schedule. When exposure to the FI contingency was limited (Condition 2), the proportion of FI earned reinforcers did not exceed .2 at any dose under the alternative FR 50 FI 90-s schedule. Nevertheless, proportion of FI reinforcers under methadone slightly exceeded saline values. Although increases in FI

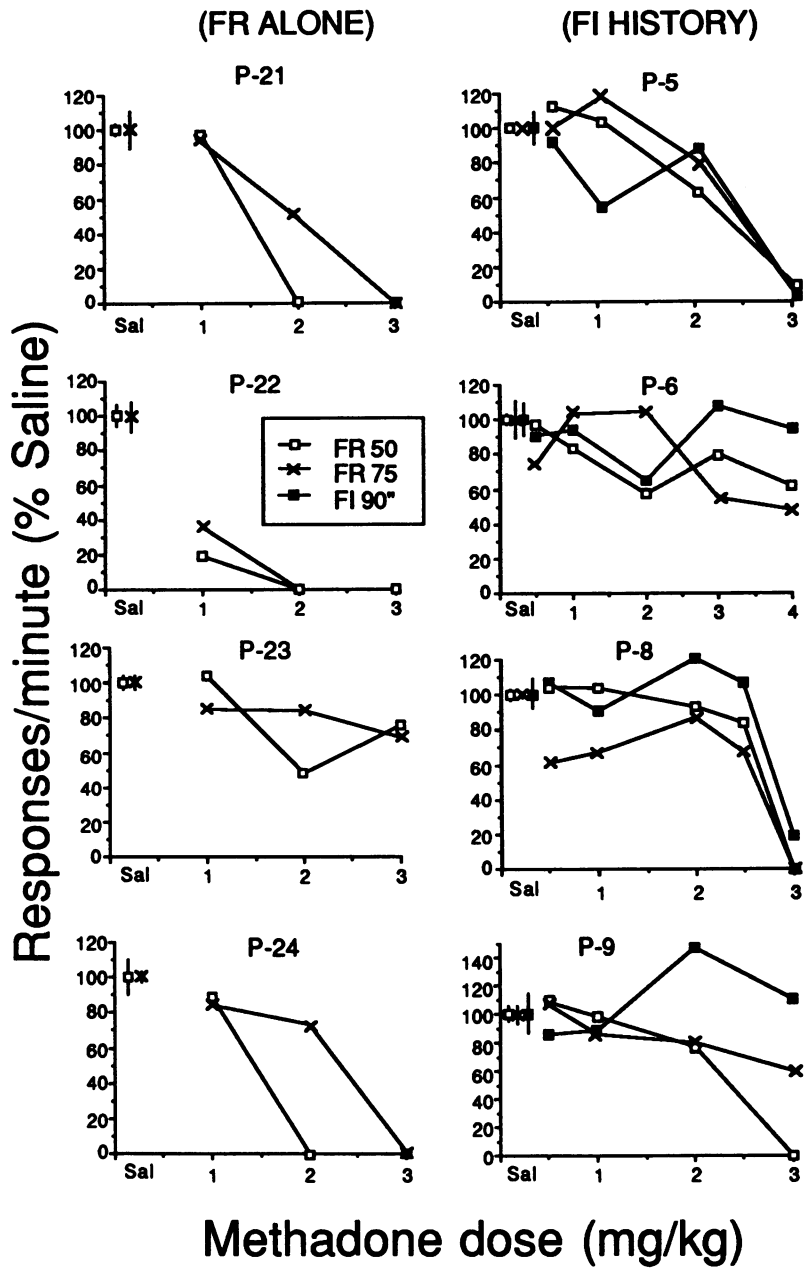


Fig. 4. Effects of methadone on key-peck rates under FR 50, FR 75, and FI 90-s (Condition 4 only) schedules. Detached points to the extreme left denote mean saline measures under each schedule ±*SEM*.

reinforcement were greater under the alternative FR 75 FI 90-s schedule for Condition 2, this effect was not as pronounced as that associated with the first condition (Figure 5, second row).

The bottom half of Figure 5 shows methadone's effects on the proportion of reinforcers earned 90 s or more after the previous reinforcer when FR 50 and FR 75 schedules did not appear in the context of the alternative FR FI schedule. Because proportions were derived from values that were fairly uniform across subjects and dose, total session reinforcers will be summarized briefly for Conditions 3 and 4.

Table 1

Mean key-peck rates (pecks per minute) under saline for each schedule condition.

| | Condition 1 | | | | Condition 2 | | | | Condition 3 | | | | Condition 4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P-164 | P-10 | P-11 | P-12 | P-1 | P-2 | P-4 | | P-21 | P-22 | P-23 | P-24 | P-5 | P-6 | P-8 | P-9 |
| Schedule | | | | | | | | Schedule | | | | | | | | |
| ALT FR 50 FI 90 s | | | | | | | | FR 50 | | | | | | | | |
| *M* | 126 | 118 | 132 | 92 | 68 | 96 | 113 | *M* | 109 | 131 | 138 | 117 | 110 | 157 | 114 | 99 |
| *SEM* | 5 | 6 | 10 | 7 | 7 | 8 | 2 | *SEM* | 4 | 9 | 7 | 11 | 0 | 1 | 1 | 1 |
| ALT FR 75 FI 90 s | | | | | | | | FR 75 | | | | | | | | |
| *M* | 98 | 103 | 154 | 95 | 67 | 94 | 99 | *M* | 105 | 130 | 142 | 116 | 93 | 144 | 117 | 95 |
| *SEM* | 14 | 14 | 11 | 14 | 11 | 14 | 2 | *SEM* | 11 | 13 | 7 | 4 | 1 | 2 | 7 | 2 |
| ALT FR 200 FI 90 s | | | | | | | | FI 90 s | | | | | | | | |
| *M* | 64 | 70 | 85 | 49 | — | — | — | *M* | — | — | — | — | 65 | 88 | 85 | 67 |
| *SEM* | 11 | 4 | 10 | 7 | | | | | | | | | | | | |

For subjects in Condition 3, total session reinforcers under saline ranged from 83 to 110 ($M$ = 95) for the FR 50 schedule and from 52 to 80 ($M$ = 67) under the FR 75 schedule. Methadone reduced total session reinforcers from the saline range on three occasions (P-22, FR 50, 1.0 mg/kg: 22 reinforcers per session; P-22, FR 75, 1.0 mg/kg: 27 reinforcers per session; P-23, FR 50, 2.0 mg/kg: 55 reinforcers per session). Under Condition 4, total session reinforcers under the FR 50 ranged from 86 to 146 ($M$ = 109), and, under the FR 75, from 53 to 107 ($M$ = 70). For those subjects, methadone engendered substantial deviations from the saline ranges on two occasions (P-5, FR 50, 3.0 mg/kg: 5 reinforcers per session; P-9, FR 75, 3.0 mg/kg: 33 reinforcers per session). For Condition 3, there was only one instance in which the proportion of reinforcers occurring 90 s since the previous reinforcer exceeded .1 (P-22 under the FR 50 schedule at 1.0 mg/kg methadone). When methadone was administered to subjects with an FI 90-s schedule history (Condition 4), a slight increase in the proportion of reinforcers occurring 90 s since the previous reinforcer occurred under the FR 75 schedule. However, the reinforcement requirement was almost always fulfilled before 90 s since the previous reinforcement had elapsed under each methadone session. For Conditions 3 and 4, most interreinforcement periods greater than 90 s resulted from pausing at the beginning of the session (i.e., a warm-up effect).

Figure 6 shows effects of methadone on the proportion of total session reinforcers earned under the FI 90-s component of the alternative FR 200 FI 90-s schedule by pigeons in Condition 1. Under saline, nearly all reinforcers were earned by fulfilling the FI 90-s requirement. For Subject P-11, 0.5 mg/kg and 1.0 mg/kg methadone decreased the proportion FI reinforcers, whereas the other subjects' performances were unchanged.

## DISCUSSION

Operant performance typical of that maintained under a basic reinforcement schedule may be embedded among several latent variables, the influence of which is not apparent. The importance of these latent factors may become obvious only when a third variable is introduced. Such changes can be engendered by genetic factors (Wimer & Wimer, 1985), differences in history (Barrett, 1985; Weiner, 1964), or manipulation of reinforcer value (Dickinson, Nicholas, & Adams, 1983). The present experiment examined the manner in which performances apparently maintained under one schedule (FR) are perturbed by a drug to reveal the influence of another simultaneously operative set of controlling variables (FI schedule), even though the effects of the latter contingency were not apparent in the baseline performance. These investigations have also analyzed several conditions necessary to reveal the multiple controlling factors present under alternative schedules.

Alternative reinforcement schedules involve features lending themselves to the exploration of such latent variables. Under alternative schedules in which the fixed-ratio value is large relative to a given fixed-interval size, perfor-

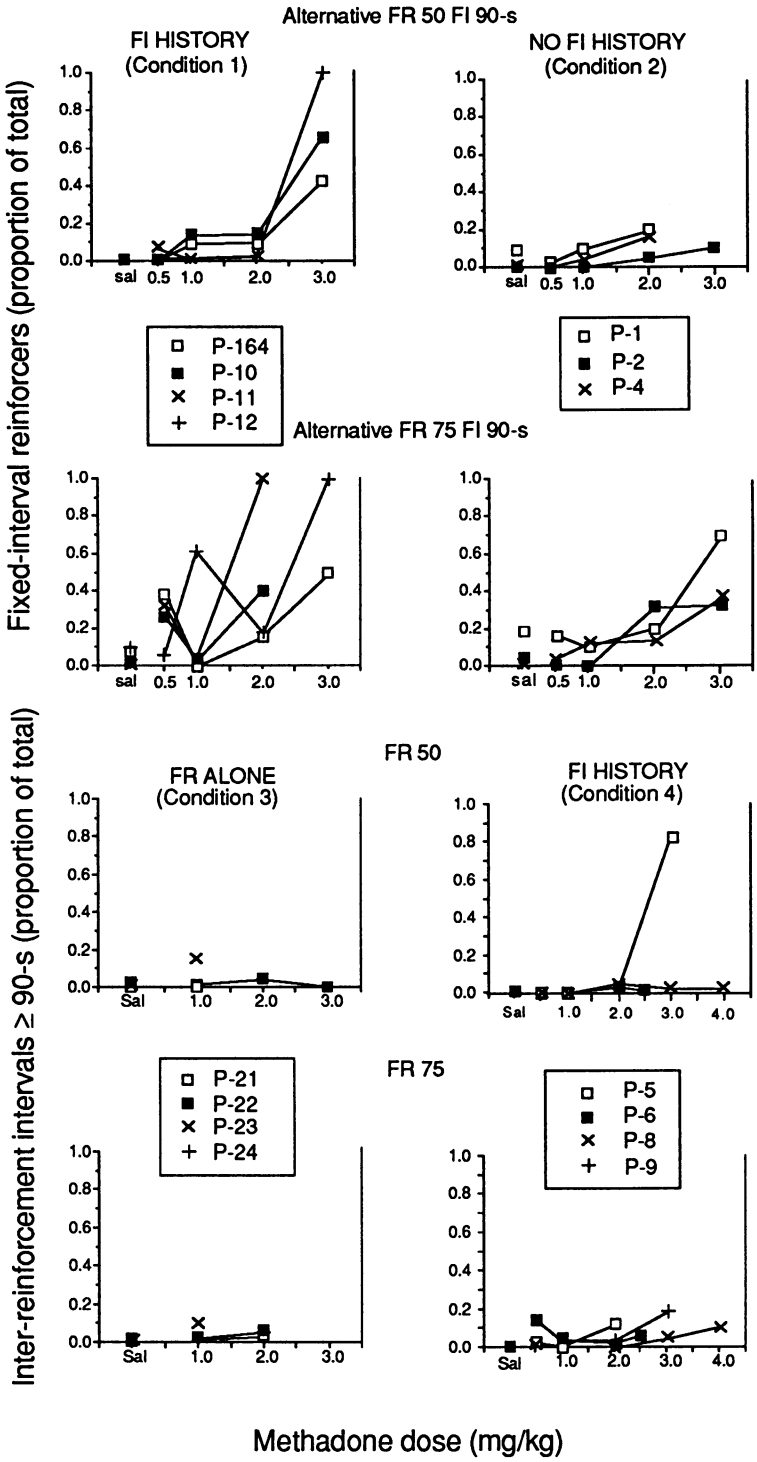


Fig. 5. The proportion of total session reinforcers earned by fulfilling the FI 90-s contingency by subjects in Condition 1 (top left) and Condition 2 (top right) as a function of methadone dose for the alternative FR 50 FI 90-s schedule (top row) and alternative FR 75 FI 90-s schedule (second row). Also, the proportion of total session reinforcers occurring at intervals of 90 s or greater under FR 50 (third row) and FR 75 (bottom row) schedules for subjects in Condition 3 (bottom left) and Condition 4 (bottom right) as a function of methadone dose. See text for explanation of the conditions.

Table 2

Number of reinforcers earned under the FI schedule over total number of reinforcers for Condition 1 (proportions are shown in parentheses).

| | P-164 | | | P-10 | | |
|---|---|---|---|---|---|---|
| | FR 50 | FR 75 | FR 200 | FR 50 | FR 75 | FR 200 |
| Saline | 0/99 (0) | 8/45 (.18) | 20/28 (.71) | 0/87 (0) | 2/44 (.04) | 27/27 (1) |
| 0.5 mg/kg methadone | 0/105 (0) | 15/40 (.26) | 26/28 (.93) | 0/77 (0) | 9/35 (.26) | 28/28 (1) |
| Saline | 0/91 (0) | 3/63 (.05) | 25/28 (.89) | 0/98 (0) | 0/58 (0) | 28/28 (1) |
| 1 mg/kg methadone | 5/57 (.09) | 0/64 (0) | 28/28 (1) | 6/48 (.13) | 1/45 (.02) | 28/28 (1) |
| Saline | 0/104 (0) | 0/65 (0) | 28/28 (1) | 0/84 (0) | 0/47 (0) | 26/28 (.93) |
| 2 mg/kg methadone | 5/49 (.10) | 6/37 (.16) | 26/28 (.93) | 5/37 (.14) | 11/27 (.41) | 28/28 (1) |
| Saline | 0/92 (0) | 4/52 (.08) | 28/28 (1) | 0/99 (0) | 0/75 (0) | 28/28 (1) |
| 3 mg/kg methadone | 15/35 (.43) | 15/30 (.50) | 28/28 (1) | 4/6 (.66) | — | 14/14 (1) |
| Saline *M* | 0 | .08 | .90 | 0 | .01 | .98 |
| *SEM* | 0 | .04 | .08 | 0 | .01 | .02 |

mance resembles that maintained under a simple fixed-interval schedule (cf. Rider, 1980; Condition 1 in this investigation). Whether the FR contingency has any influence in controlling performance under an alternative schedule with a very large FR size is unclear, because the performance appears to be totally regulated by the FI contingency. Conversely, under an alternative schedule with a small FR size, it remains ambiguous whether the FI contingency has any influence (i.e., the performance may be totally controlled by the small FR schedule).

In the present experiments, methadone administration disrupted control by the predominant schedule variable within an alternative FR FI schedule. In Condition 1, methadone increased the proportion of reinforcers earned by satisfying the FI 90-s contingency as a direct function of FR size and methadone dose (Figure 5). Cumulative records of key pecking by some pigeons following methadone administration were consistent with control by components of the FI contingency, whereas such an influence was less obvious in the performance of others (Figure 1).

Under Condition 1, prior exposure to the FI schedule (via the alternative FR 200 FI 90-s schedule) may have been responsible for the appearance of FI-like performance following methadone administration, rather than features of the alternative FR FI schedule per se. Alternatively, because methadone is known to reduce overall response rates, the increased number of instances in which reinforced responses occurred 90 s or more apart (i.e., the size of the FI schedule in the present experiment) may have created the appearance of greater control by the FI schedule, although actually being an artifact of methadone induced key-peck rate reductions.

Two conditions were carried out to explore the role of a history of exposure to the FI contingency as a determinant of the subsequent control by that contingency following methadone administration. In Condition 2, the birds were trained only under the FR 50 and FR 75 schedules and were exposed to the alternative FR 50 FI 90-s or alternative FR 75 FI 90-s schedule once weekly during methadone test days. Under the alternative FR 50 FI 90-s schedule, the proportion of FI earned reinforcers did not exceed .2 at any dose. When the alternative FR 75 FI 90-s schedule was used, the proportion of FI reinforcers exceeded .4 on only one occasion. Thus, limiting exposure to the FI contingency embedded within an alternative schedule appeared to reduce the influence of this latent schedule effect.

Methadone usually reduces overall response rates, especially under FR schedules (e.g., Thompson et al., 1984). Methadone administration, therefore, could have increased interresponse times to the point that the birds

Table 2
(*Continued*)

| P-11 | | | P-12 | | |
|---|---|---|---|---|---|
| FR 50 | FR 75 | FR 200 | FR 50 | FR 75 | FR 200 |
| 1/95 (.01) | 0/75 (0) | 25/29 (.86) | 0/69 (0) | 0/62 (0) | 28/28 (1) |
| 1/72 (.01) | 16/49 (.33) | 20/30 (.67) | 3/41 (.07) | 2/43 (.05) | 28/28 (1) |
| 0/95 (0) | 0/92 (0) | 28/28 (1) | 0/66 (0) | 12/34 (.35) | 28/28 (1) |
| 1/75 (.01) | 1/68 (.01) | 19/31 (.61) | 0/50 (0) | 18/29 (.62) | 28/28 (1) |
| 1/98 (.01) | 0/87 (0) | 16/34 (.47) | 1/74 (.01) | 2/52 (.04) | 28/28 (1) |
| 1/72 (.01) | 25/25 (1) | 28/28 (1) | 1/52 (.02) | 6/35 (.17) | 28/28 (1) |
| 0/99 (0) | 0/75 (0) | 23/29 (.79) | 0/87 (0) | 0/59 (0) | 28/28 (1) |
| — | — | 18/18 (1) | 11/11 (1) | 28/28 (1) | 28/28 (1) |
| 0 | 0 | .78 | 0 | .10 | 1.0 |
| 0 | 0 | .13 | 0 | .10 | 1.0 |

could not reliably complete 50 key pecks (under the FR 50 schedule) or 75 key pecks (under the FR 75 schedule) before the 90-s interval had elapsed. Indeed key-peck rate decreases were associated with methadone doses that engendered increased reinforcement under the FI component of the alternative schedule (see Figure 4). Under such conditions, more reinforcers would have been earned by satisfying the FI contingency, but that would not necessarily mean that the latter contingency was exercising more control. It would simply mean that key-peck rates had dropped to a very low level. In Condition 3, this idea was tested by training the birds under FR 50 and FR 75 schedules and then administering methadone. If the number of reinforcers earned by satisfying the FI 90-s contingency was an artifactual reflection of methadone-induced decreases in pecking, then the number of times reinforcement was earned 90 s or more apart under Condition 3 should be comparable to that in Conditions

Table 3

Number of reinforcers earned under the FI schedule over total number of reinforcers for Condition 2. (Proportions are shown in parentheses.)

| | P-1 | | P-2 | | P-4 | |
|---|---|---|---|---|---|---|
| | FR 50 | FR 75 | FR 50 | FR 75 | FR 50 | FR 75 |
| Saline | 2/72 (.03) | 10/32 (.31) | 0/94 (0) | 0/62 (0) | 0/104 (0) | 3/58 (.05) |
| 0.5 mg/kg methadone | 3/68 (.04) | 7/43 (.16) | 0/101 (0) | 0/53 (0) | 1/90 (.01) | 2/52 (.04) |
| Saline | 1/69 (.01) | 1/57 (.02) | 1/66 (.02) | 0/58 (0) | 0/97 (0) | 0/58 (0) |
| 1 mg/kg methadone | 6/59 (.10) | 4/35 (.11) | 0/102 (0) | 1/45 (.02) | 2/73 (.03) | 5/42 (.12) |
| Saline | 7/57 (.12) | 8/32 (.25) | 0/93 (0) | 0/61 (0) | 0/102 (0) | 0/62 (0) |
| 2 mg/kg methadone | 6/32 (.19) | 3/15 (.20) | 3/56 (.05) | 10/32 (.31) | 5/31 (.16) | 6/42 (.14) |
| Saline | 6/48 (.13) | 7/40 (.18) | 0/90 (0) | 5/34 (.15) | 0/102 (0) | 1/59 (.02) |
| 3 mg/kg methadone | — | 7/10 (.70) | 4/37 (.12) | 3/9 (.33) | — | 11/30 (.37) |
| Saline *M* | .07 | .19 | 0 | .04 | 0 | .02 |
| *SEM* | .04 | .07 | 0 | .04 | 0 | .01 |

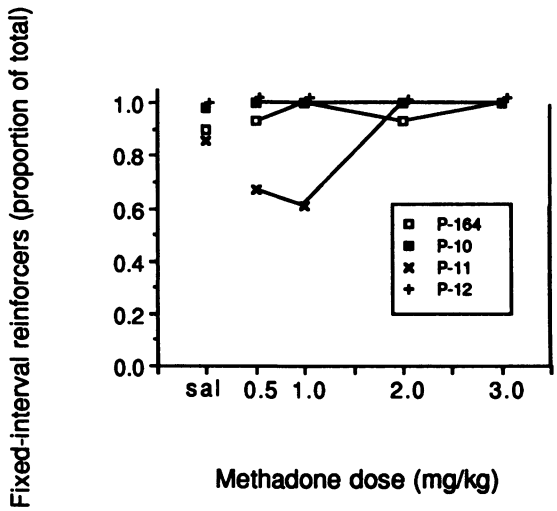


Fig. 6. The proportion of total session reinforcers earned by fulfilling the FI 90-s contingency by subjects in Condition 1 as a function of methadone dose for the alternative FR 200 FI 90-s schedule.

1 and 2. Data in the lower left portion of Figure 1 revealed that nearly all of the reinforcers were earned before 90 s since the previous reinforcer had elapsed. In short, the possibility that the increase in FI earned reinforcers was an artifact of lowered key-peck rates produced by methadone appears unlikely.

The question remains as to whether prolonged pausing under the FR contingency requires that the birds have prior experience with an FI schedule for the latent influence of the FI contingency to be seen when methadone is administered. Weiner (1969) showed that a history of low-rate responding was necessary for subsequent exposure to an FI contingency to engender low response rates. This question was explored in Condition 4 by giving birds equal prior exposure to FI 90-s, FR 50, and FR 75 schedules and examining whether methadone would engender pausing under the FR 50 and FR 75 schedules to the extent that the proportion of reinforcers earned 90 s or more apart would increase. Once again, reinforcers were rarely earned 90 s or more apart by birds with an FI 90-s history outside the context of the alternative schedule. Although key-peck rates decreased following methadone administration (Figure 4), the decrements were not sufficient to account for an increase in reinforcers earned 90 s or more apart under the first condition. The possibility that increased FI reinforcers earned under an alternative FR FI schedule were artifactually due to prolonged pausing under FR schedules is ruled out as a result.

Because changes in key-peck rate following methadone administration may influence the degree to which reinforcement is earned under the FI schedule, these data were analyzed (Figures 3 and 4). Under the first condition, methadone decreased pecking under the alternative FR 50 FI 90-s and alternative FR 75 FI 90-s schedules at doses not affecting pecking under the alternative FR 200 FI 90-s schedule (Figure 3). This finding seems to contradict reports indicating that higher density reinforcement schedules are more resistant to rate-changing effects of drugs than lower density schedules (e.g., Dews, 1955; Lucki & DeLong, 1983). Figure 6 indicates, however, that nearly all reinforcer presentations under the alternative FR 200 FI 90-s schedule were earned by fulfilling the FI contingency. In addition, response patterns observed under this schedule (Figure 2), as well as low baseline key-peck rates (Table 1), suggest that the alternative FR 200 FI 90-s schedule was effectively functioning as an FI 90-s schedule under baseline conditions. Although key-peck rates under the alternative FR 200 FI 90-s schedule were affected to a lesser degree than the other schedules, differences in predominant reinforcement contingency (FI vs. FR) may not be the sole source of this difference. Table 1 indicates that baseline response rates under the alternative FR 200 FI 90-s schedule were substantially lower than those under the alternative FR 50 FI 90-s and alternative FR 75 FI 90-s schedules. Nevertheless, exposure to the FI contingency via the alternative FR 200 FI 90-s schedule produced an amelioration of key-peck rate reductions engendered by methadone that resembles drug tolerance effects (see Figure 3).

Recent analysis of neurochemical correlates of ongoing operant behavior in pigeons indicates that cerebrospinal fluid levels of serotonin (5-HT) and dopamine (DA) metabolites are higher under the FI component of a multiple FR FI schedule (Barrett & Nader, in press). Although the present analysis cannot directly address neurochemical variables, changes in neurotransmitter activity associated

with different schedules may interact with subsequent drug administration and determine differences in the magnitude of resulting behavioral changes associated with each schedule. Indeed, differences between key-peck rate reductions under the FR contingency produced by methadone in subjects exposed to the FI schedule (Conditions 1 and 4) compared with key-peck rate reductions in subjects having no exposure to the FI contingency (Condition 3) may involve lasting changes in neurochemical activity resulting from exposure to the FI schedule (see Figures 3 and 4).

Although the recognition of latent sources of control by behavioral variables has become more common, the experimental exploitation of such factors has been limited. Drug administration may reveal the presence of latent indirect variables by unmasking the presence of those sources of behavioral control acquired via prior exposure to differing reinforcement requirements (Barrett, 1985; Nader & Thompson, 1987; Urbain et al., 1978). Even when performances of subjects with different behavioral histories are minimal, drug administration may unmask those multiple sources of schedule control. Drugs can be useful, therefore, in identifying the influences of past and current contingencies in maintaining and subsequently modifying behavior.

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